Operational Impacts of Space Weather

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MIT Lincoln Laboratory

2001 Space Control Conference

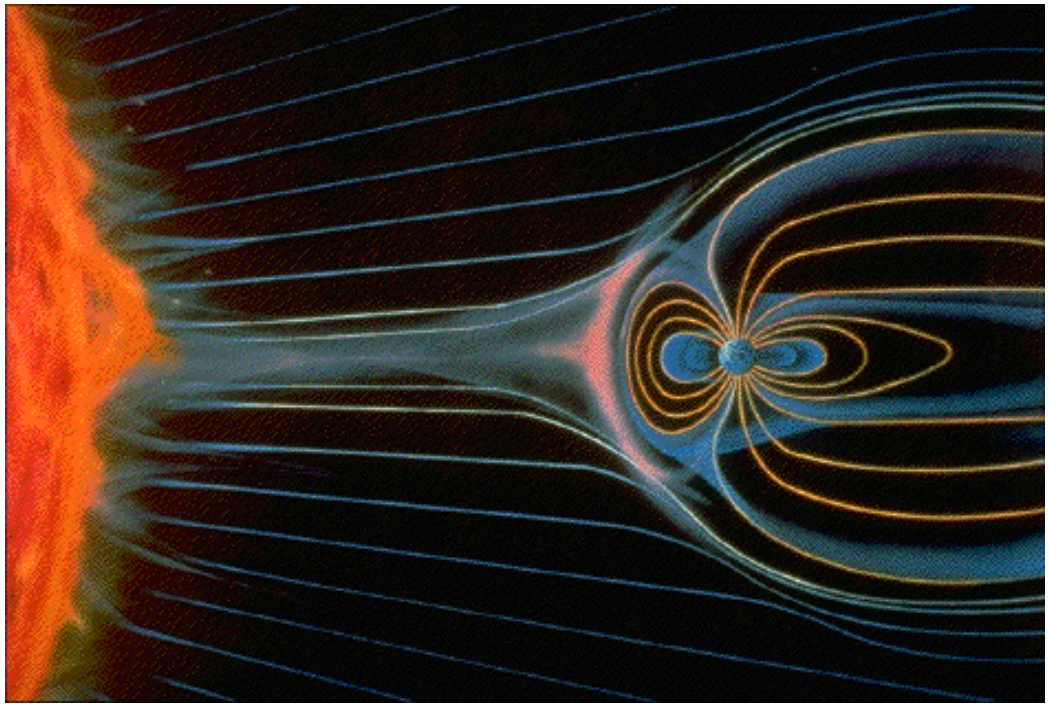
3 April 2001

Outline

- Introduction – Space Weather
- Effects on Space-Based Systems
- Effects on Ground-Based systems
- Conclusions

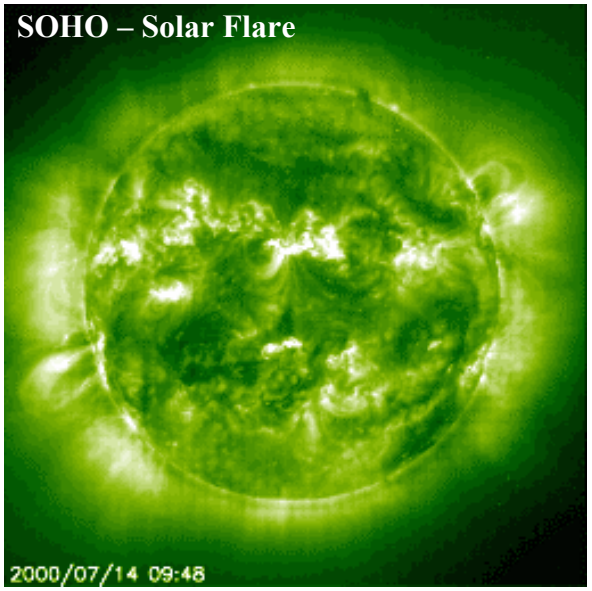
Space Weather

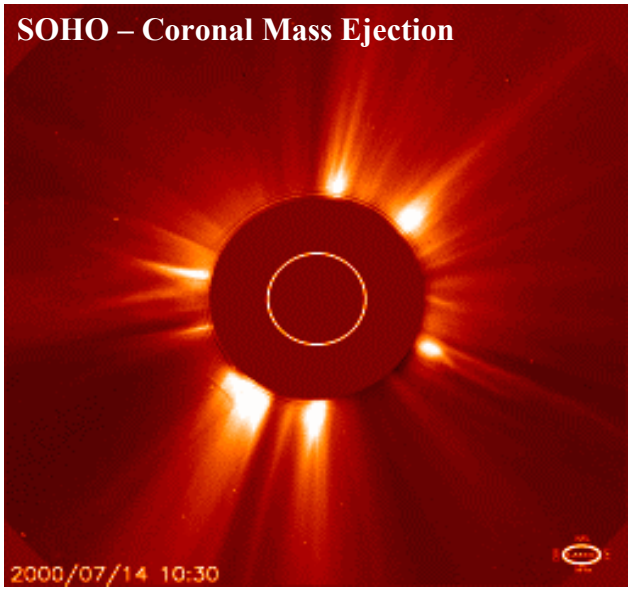
- **Definition:**
  - ***"Conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can affect performance and reliability of space-based and ground-based technological systems."****



*National.Space.Weather.Program.Strategic.Plan,.NSF

Effects of Space Weather on Earth

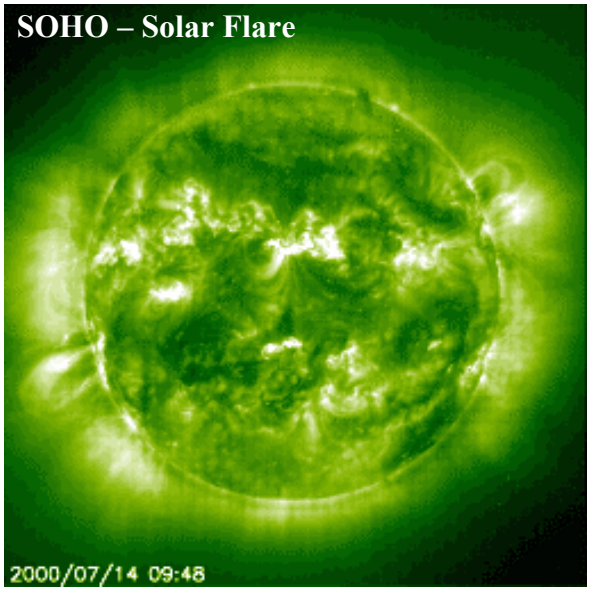


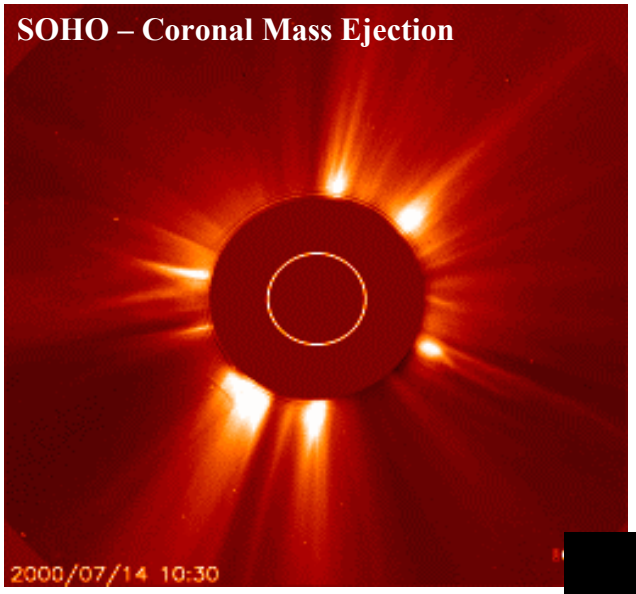


Solar Flare of 14 July 2000
Biggest Solar Storm in Nine Years

Caused very large magnetic storm and ionospheric effects

Effects of Space Weather on Earth





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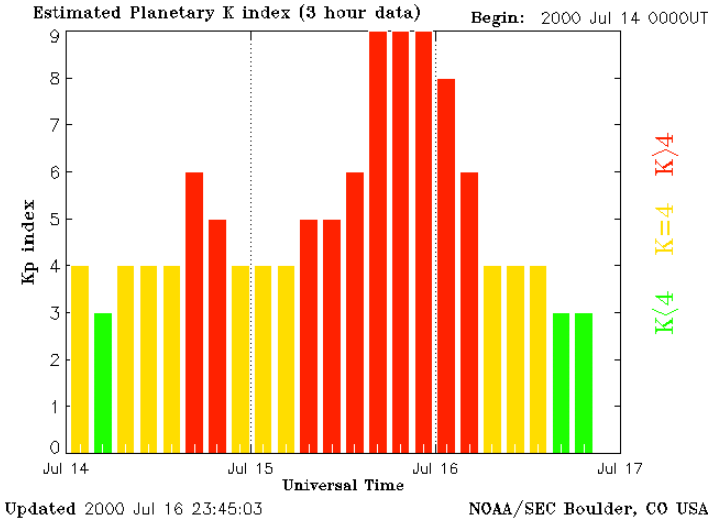

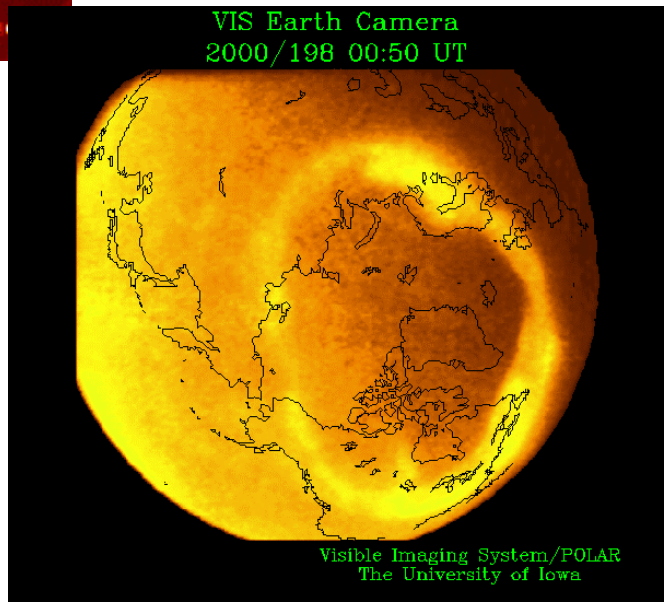

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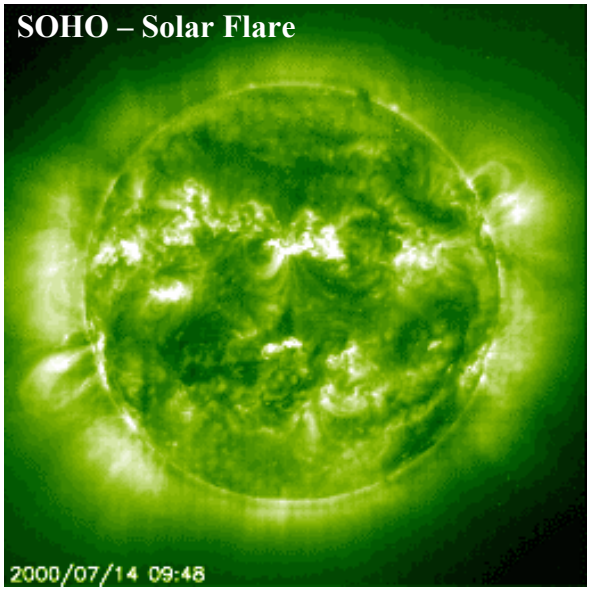

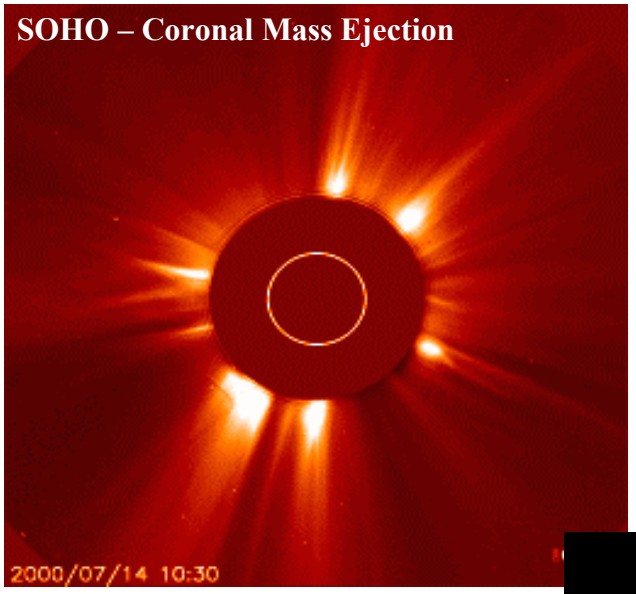

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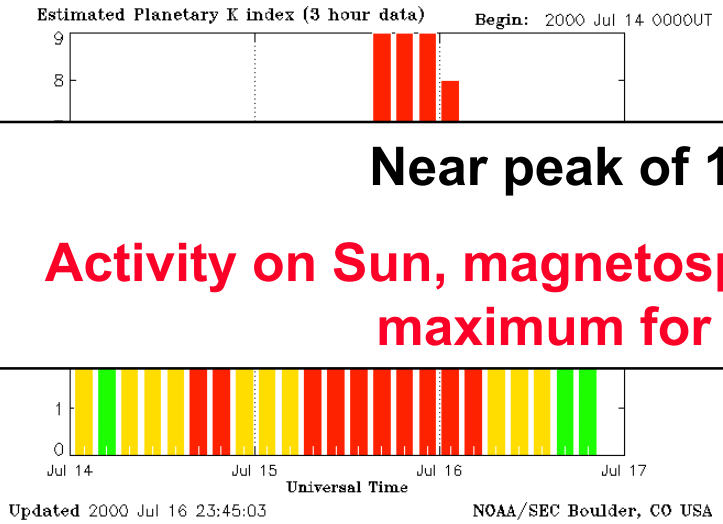


Near peak of 11 Year solar cycle

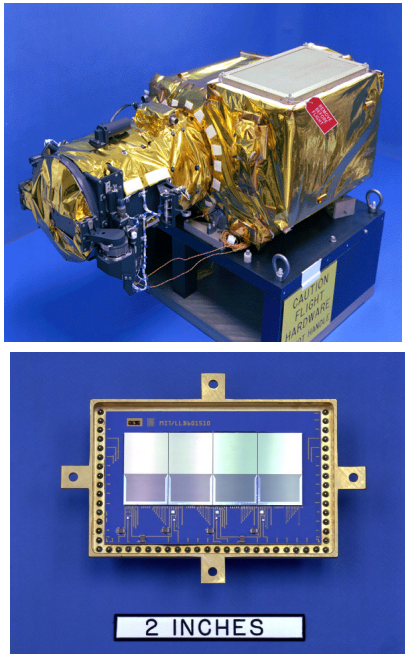
Activity on Sun, magnetosphere and ionosphere will be a maximum for the next 2-3 years

Outline

- Introduction – Space Weather
- Effects on Space-Based Systems
  - Space-Based Visible sensor
    - South Atlantic Anomaly
    - Transient effects
    - Long-term (?) effects
- Effects on Ground-Based systems
- Conclusions

Play Animation Stop

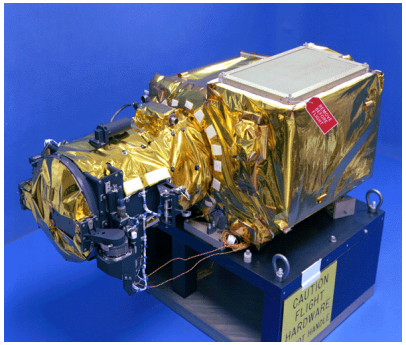
SBV Sensor

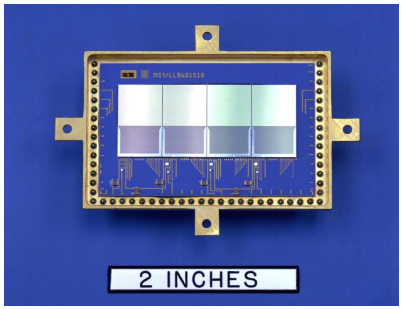


- 15 cm high straylight rejection telescope
- 4 - 420x420 Lincoln Laboratory CCD
- 1.4 x 1.4 deg field of view per CCD
- Staring sensor

Play Animation Stop

SBV Sensor





- 15 cm high straylight rejection telescope
- 4 - 420x420 Lincoln Laboratory CCD
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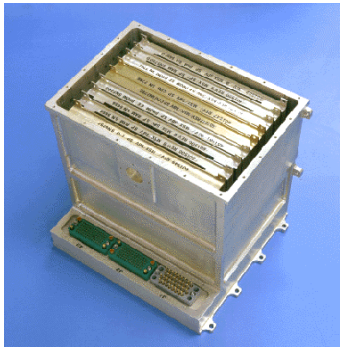
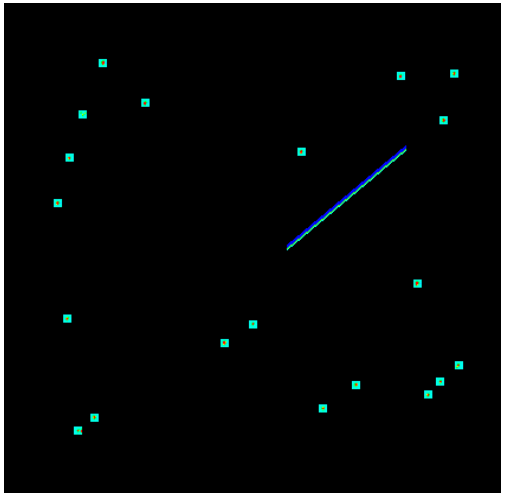
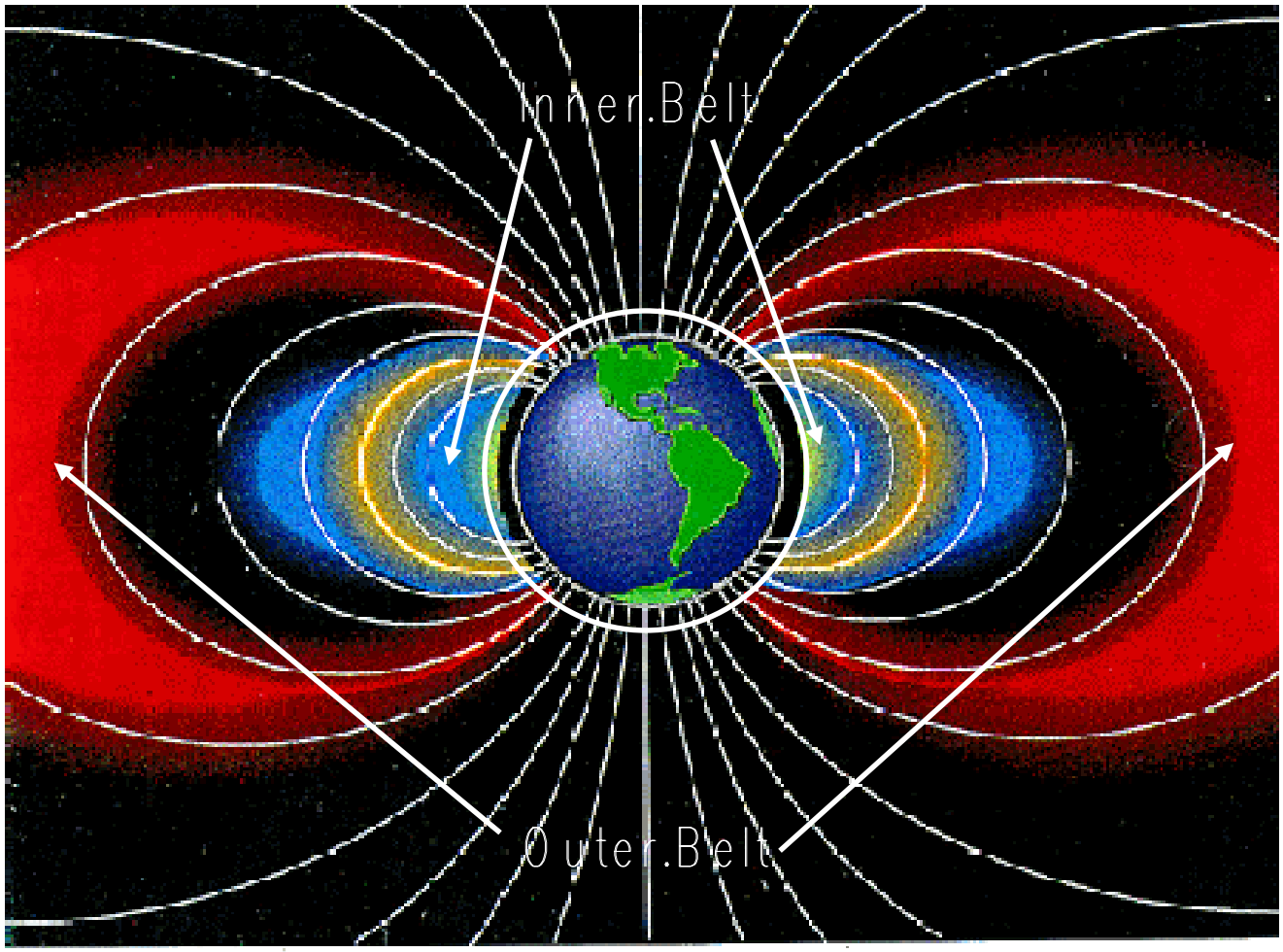
- Staring sensor

- Target and star detection
- Clutter rejection
- Data compression

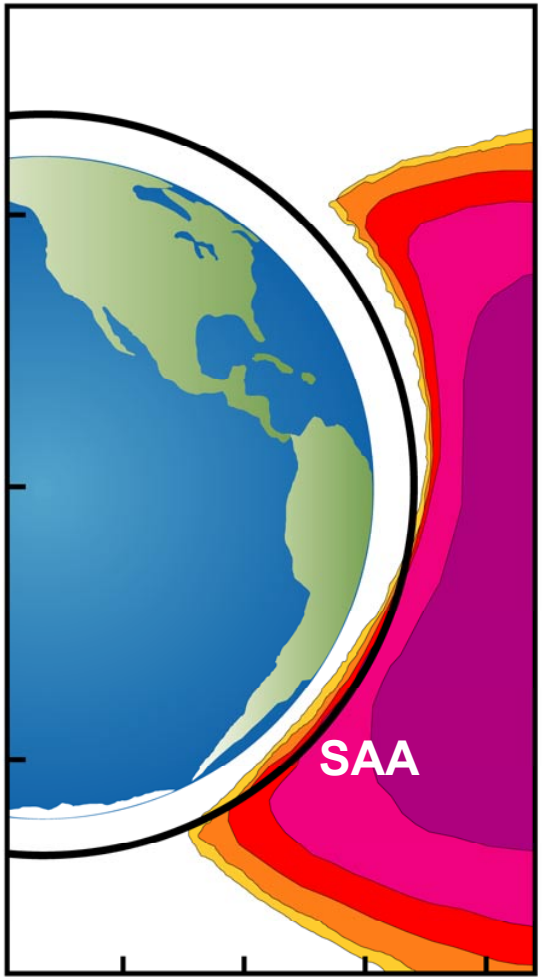




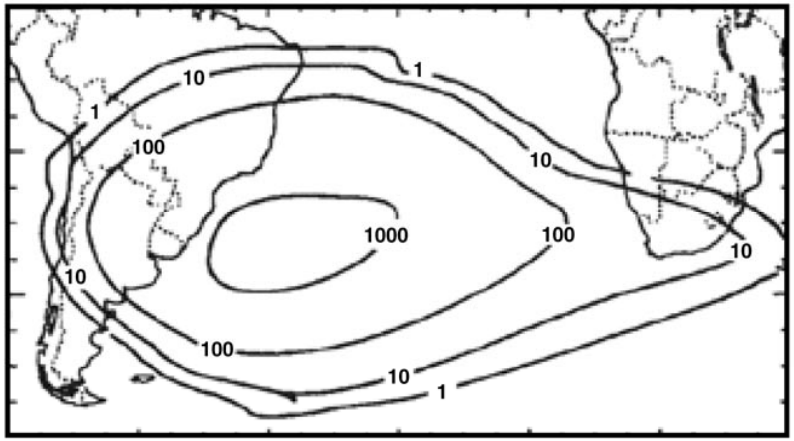
Space Environment Effects on SBV



South Atlantic Anomaly (SAA)



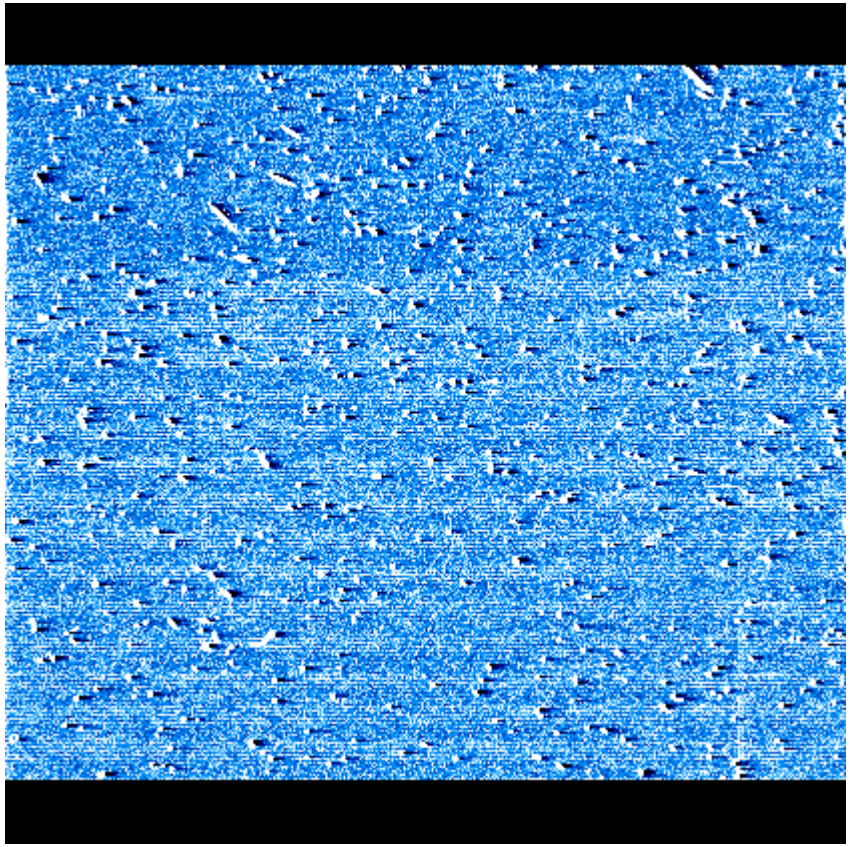
Flux contours of E > 50 MeV Protons at 500 km



Energetic particle enhancement at low altitudes due to offset of magnetic field

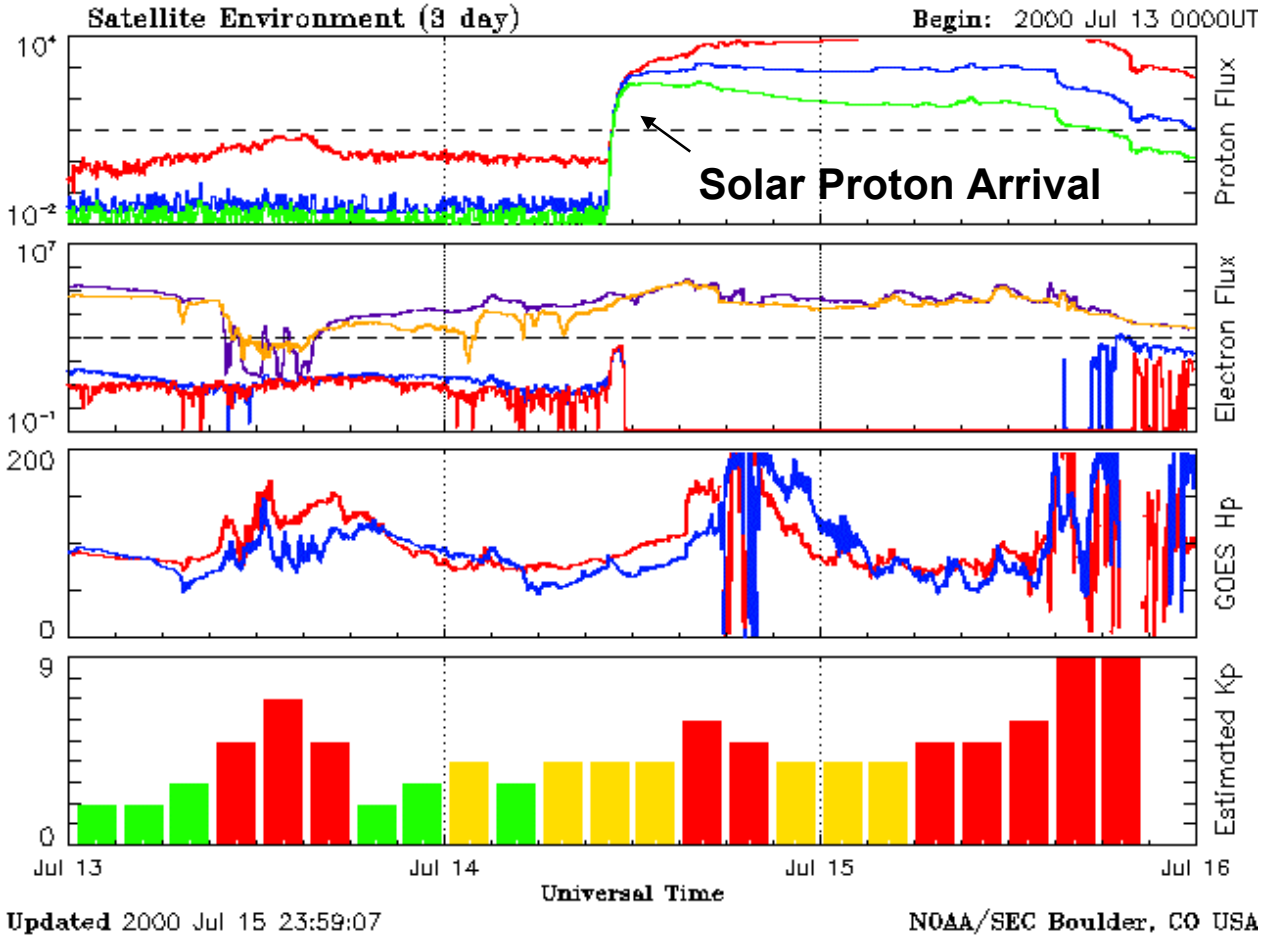
Play Animation Stop

SAA Effects on SBV



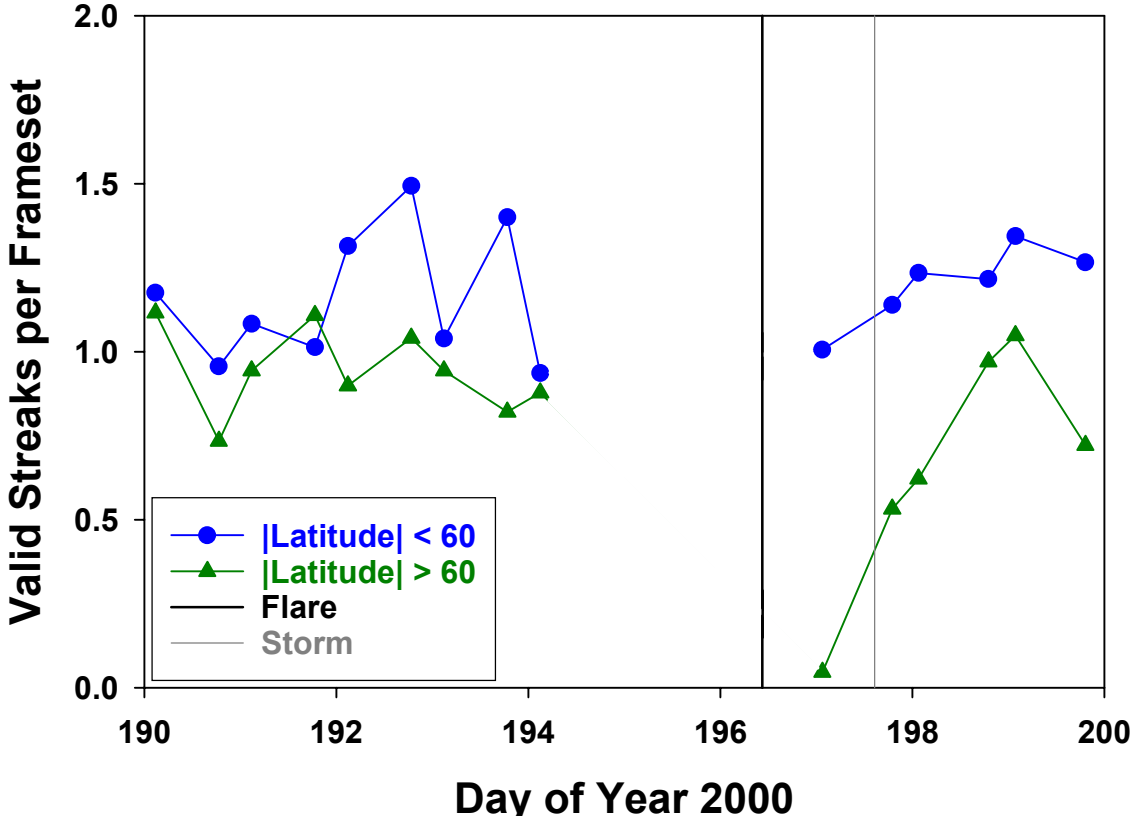
Protons with energy > 10 MeV affect SBV focal plane and inhibit ability to observe valid target streaks

Transient Effects: 14 July 2000 Solar Proton Event



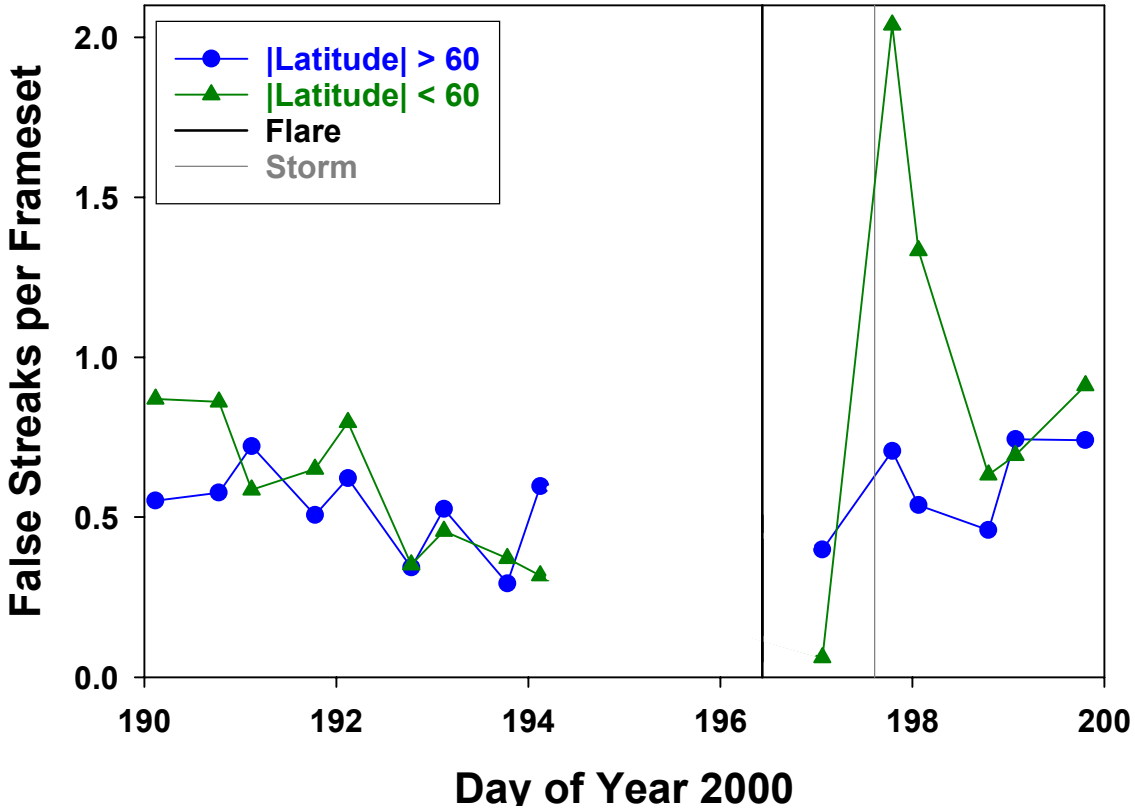
NOAA Geosynchronous Space Environment Summary

Transient Effects: 14 July 2000 Solar Proton Event



- Solar flare occurred at end of pinch point CONOPS testing
- One DCE produced no data (day 197)
- Decrease in valid streaks over polar regions seen
- Decrease not attributable to anomalies

Transient Effects: 14 July 2000 Solar Proton Event



- False streaks per frameset increased significantly after solar flare

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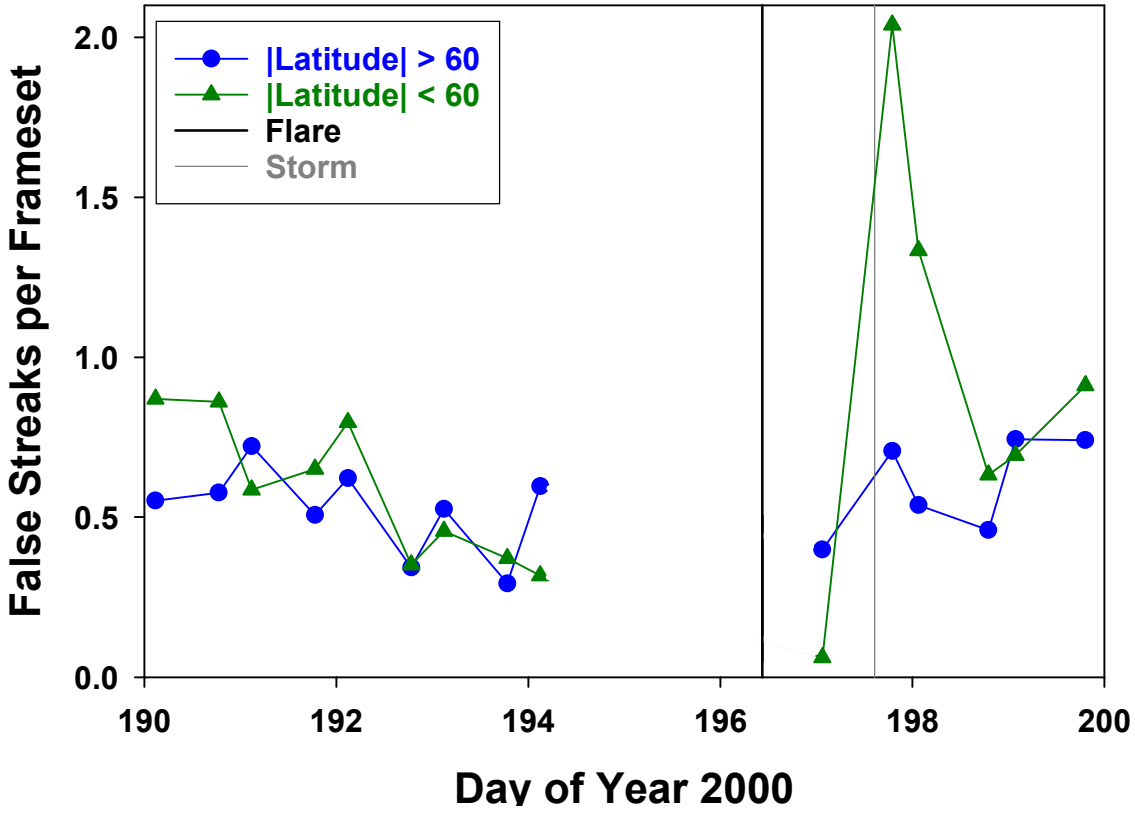
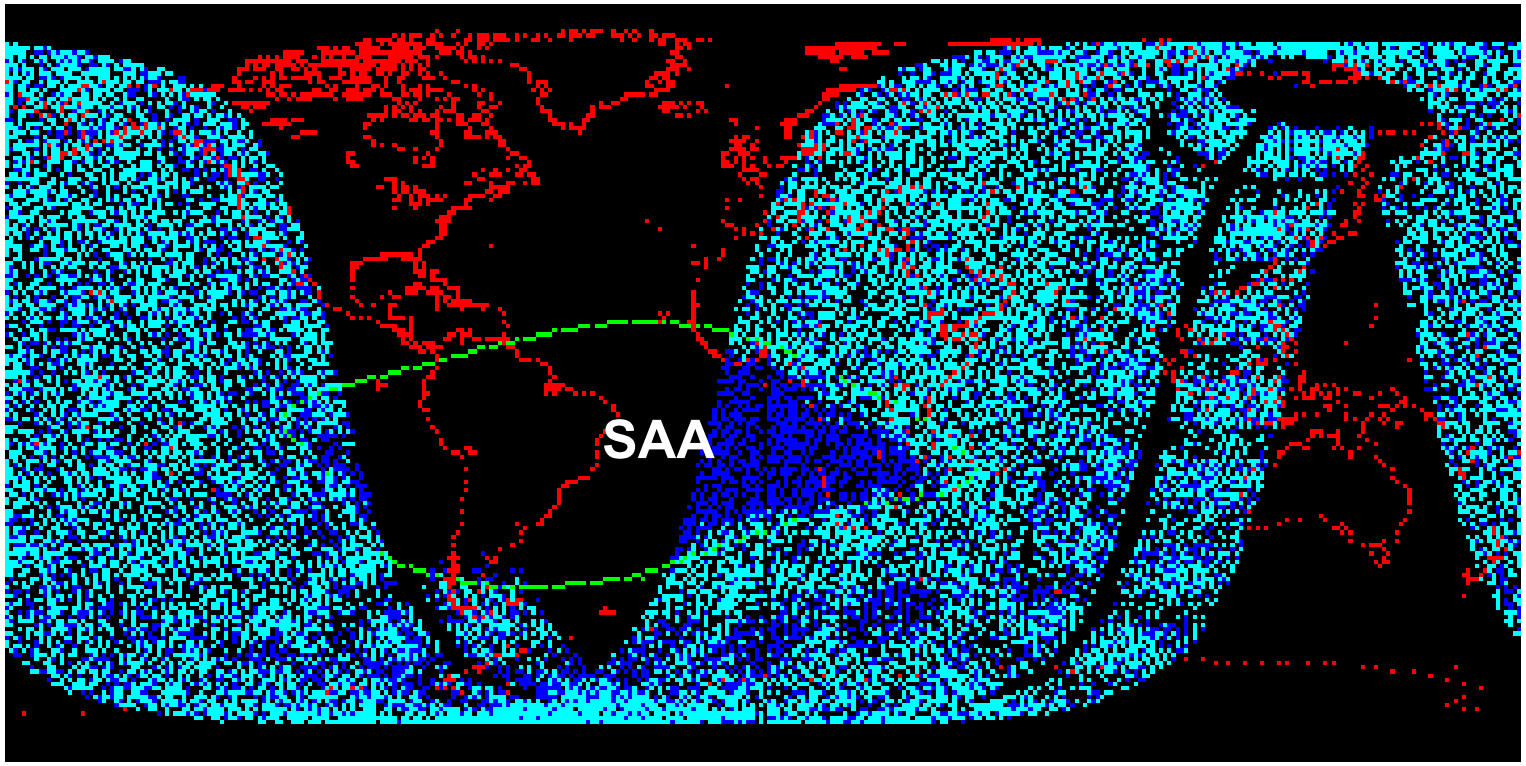


- False streaks per frameset increased significantly after solar flare

Influx of solar protons over poles degraded SBV performance

Long Term (?) Space Environment Effects



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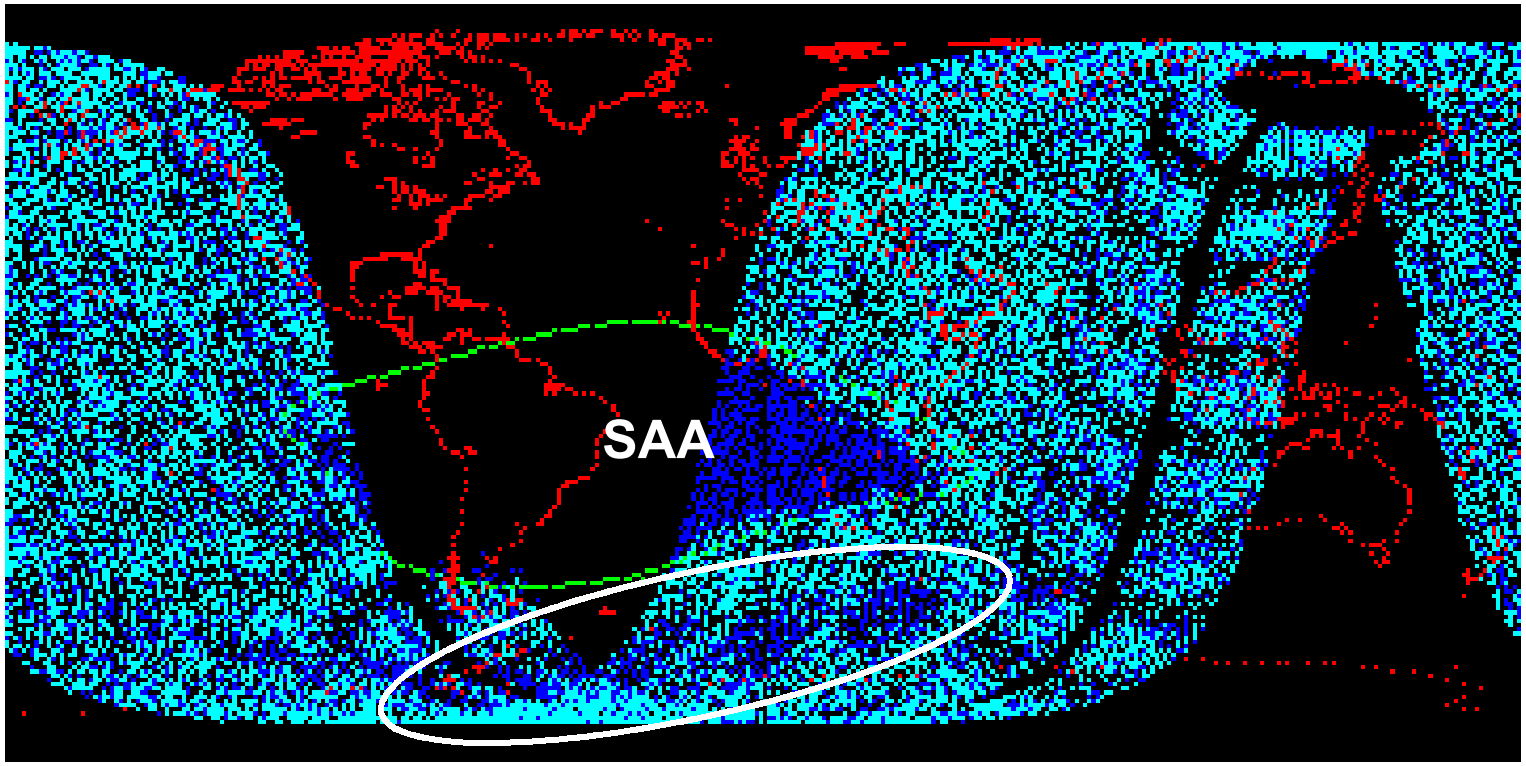

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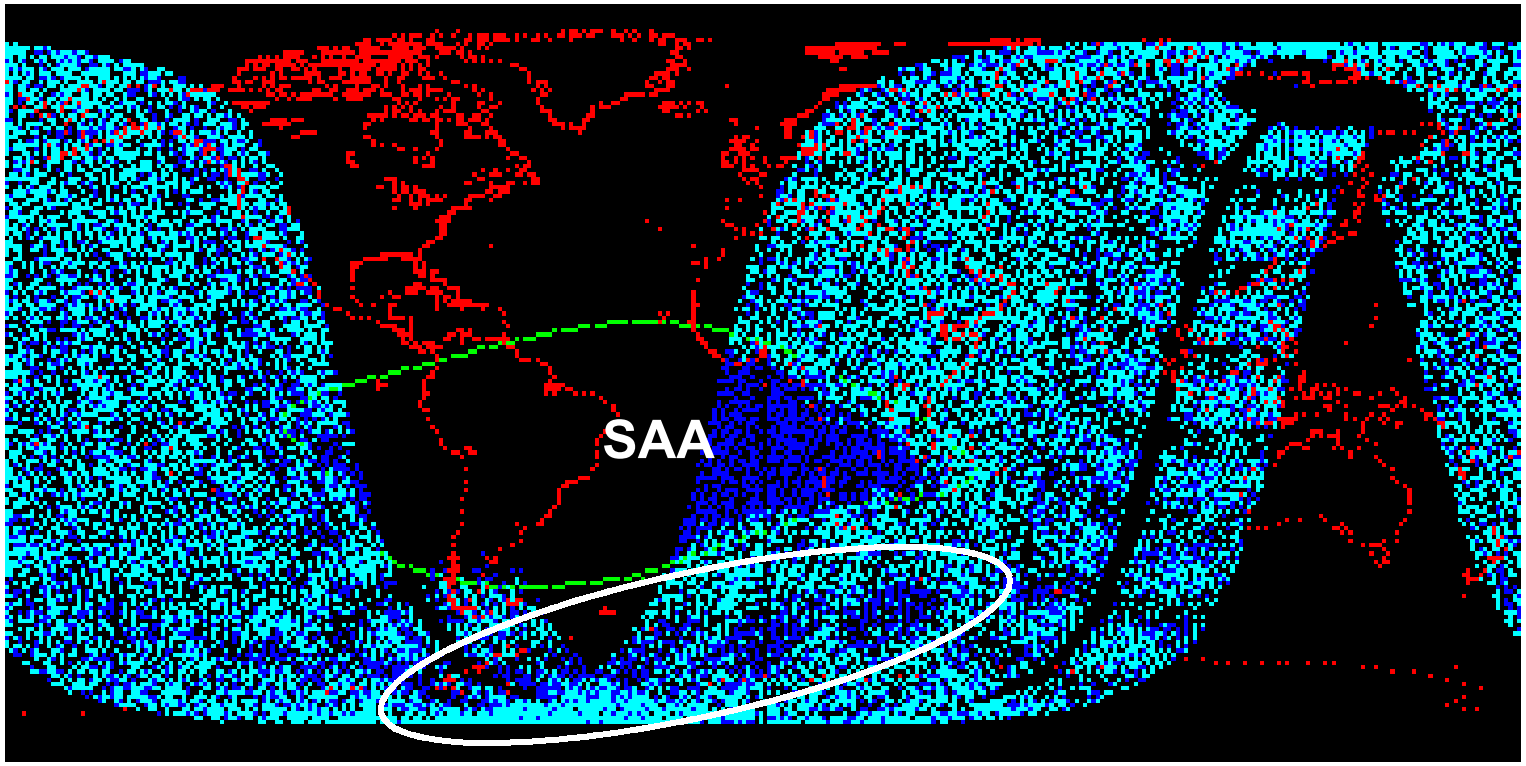
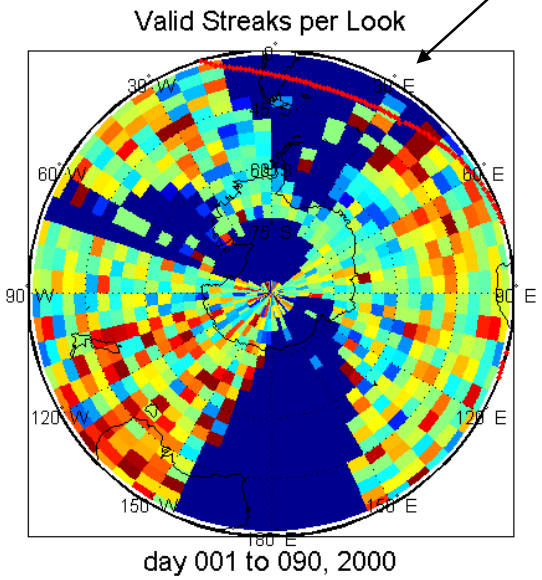
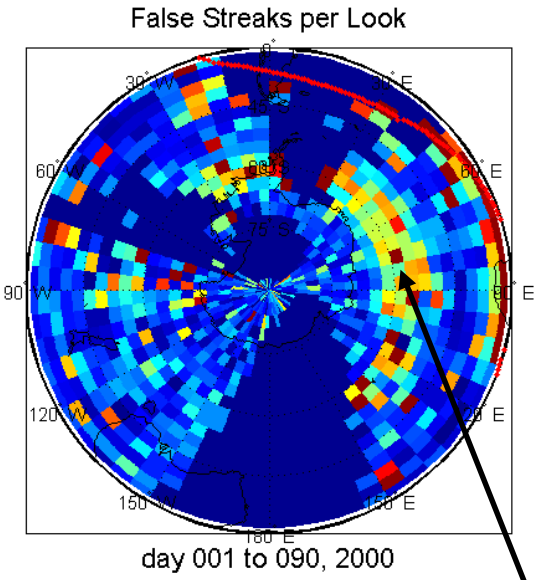


- Area with reduced detections south of SAA noticed in 1998-1999
- Effect investigated by looking geographic distribution of valid and false streaks

Long Term (?) Space Environment Effects

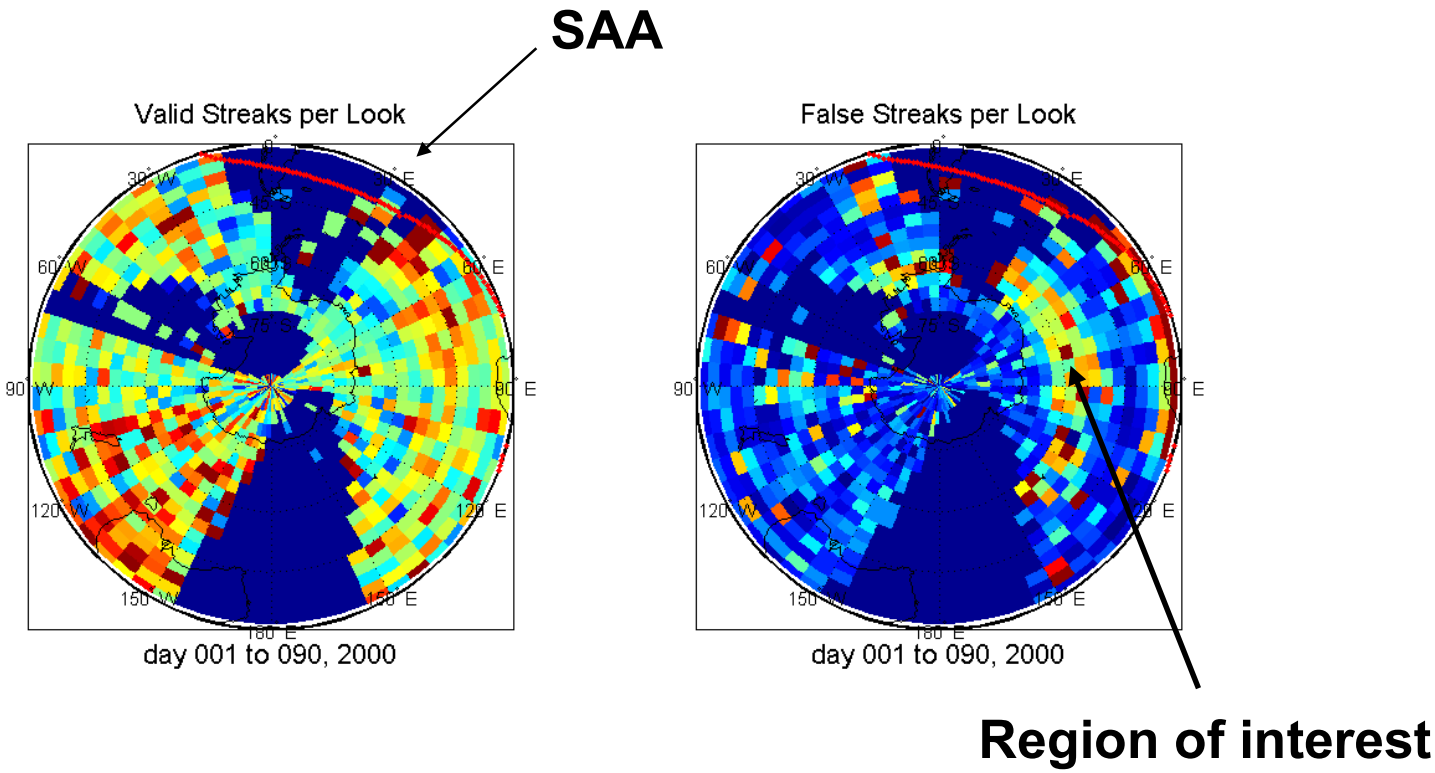
SAA





Region of interest

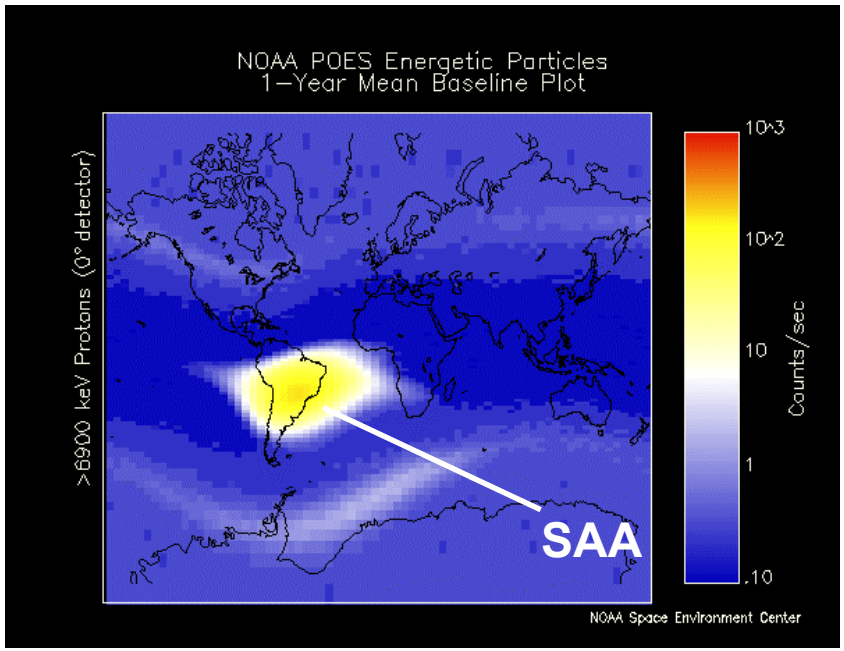
Long Term (?) Space Environment Effects



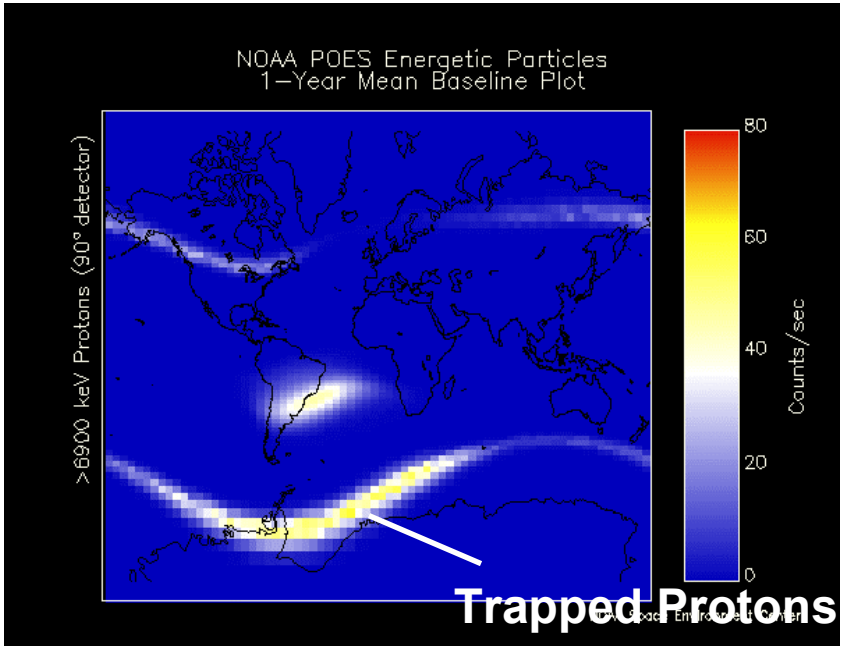
Area of degraded performance persists into 2000

Energetic Particle Source Regions

> 6900 keV proton data from NOAA POES MEPED sensor



0°-detector



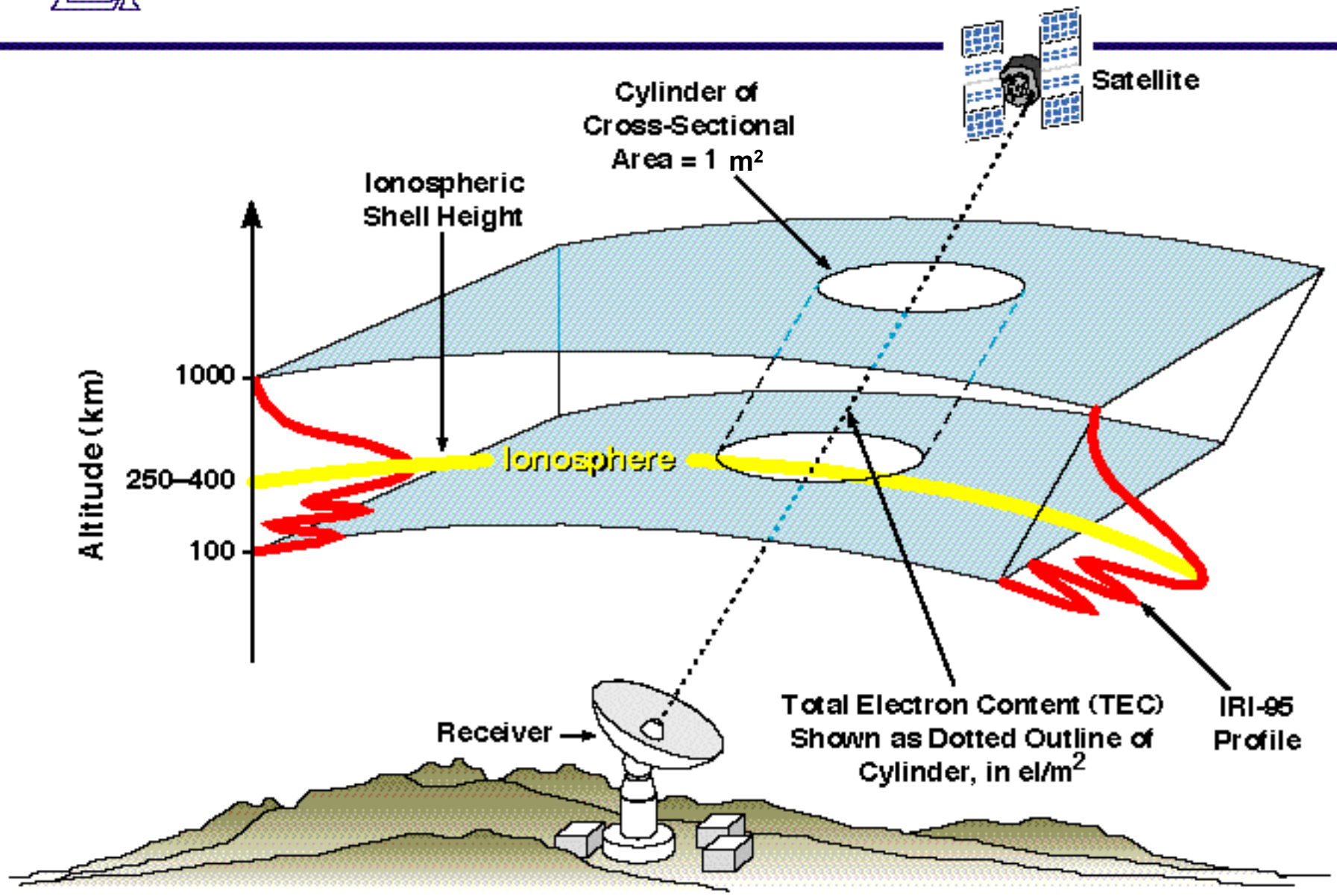
90°-detector

- NOAA baseline plots show increase in trapped outer-zone protons south of SAA in recent years
- Consistent with location of degraded SBV performance

Outline

- Introduction – Space Weather
- Effects on Space-Based systems
- Effects on Ground-Based systems
  - Range Delay
  - Scintillation
  - July 14-15th storm
- Conclusions

Ionospheric Refraction



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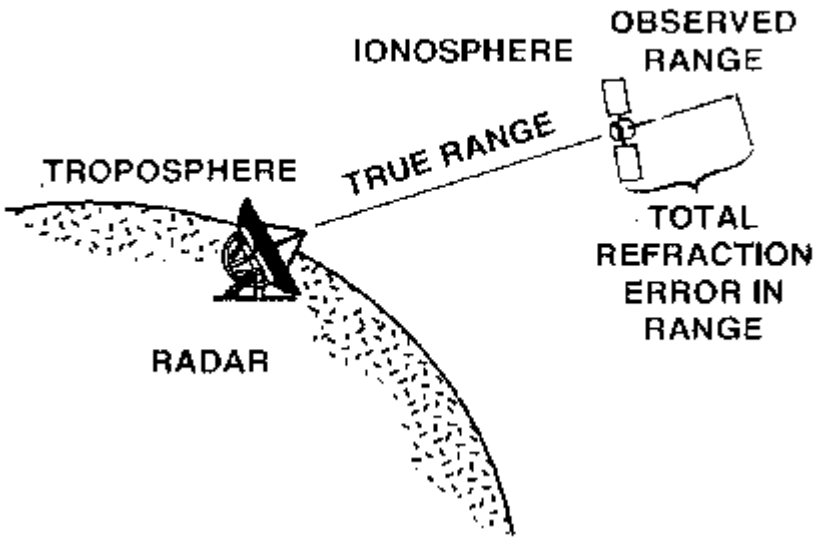
AJC 2-26-98

Illustration of Atmospheric Effects

Range Delay



$$n_{\text{ionosphere}} \approx 1 - \frac{AN_e}{f^2}$$

$$\Delta R_{ion}(meters) = \frac{40.3}{f^2} \int_0^R N_e \, dr$$

Illustration of Atmospheric Effects

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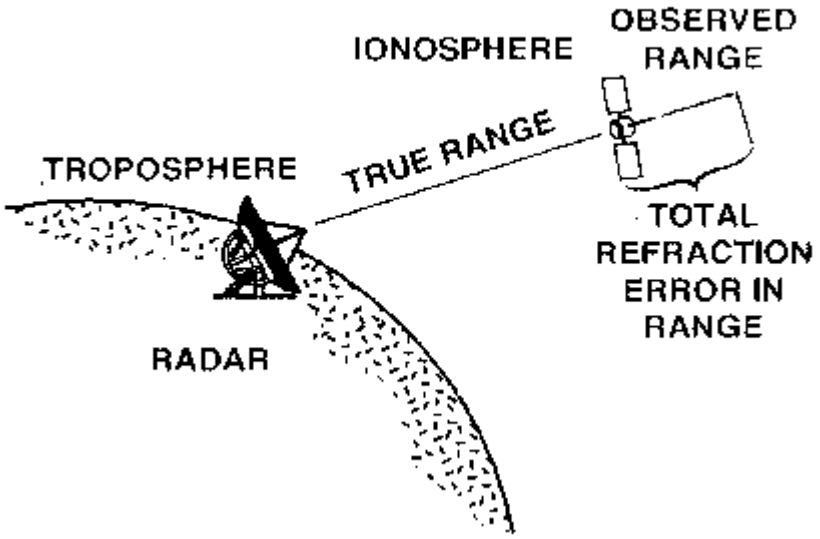

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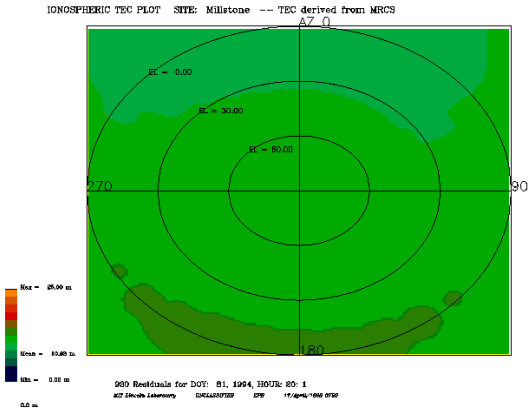
Range Delay	S-Band	L-Band	UHF	VHF	Elev
Ionosphere	6 m	32 m	280 m	2 km	< 20 °

Play Animation Stop

GRIMS: GPS Real-Time Ionospheric Monitoring System

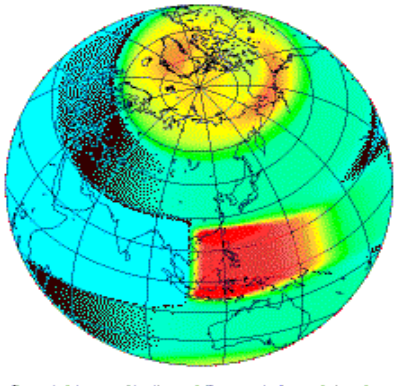
- MIT Lincoln Laboratory built the first real-time ionospheric monitoring system based on GPS (1991).
  - Purpose: Part of a radar calibration system. Operational systems online at FPS-85, ALTAIR, and Millstone satellite tracking radars.

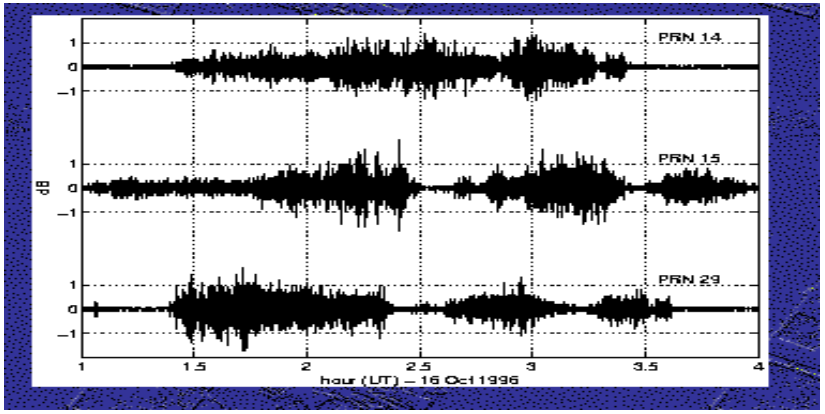
TEC as Function of Azimuth and Elevation around Millstone Hill Radar, MA



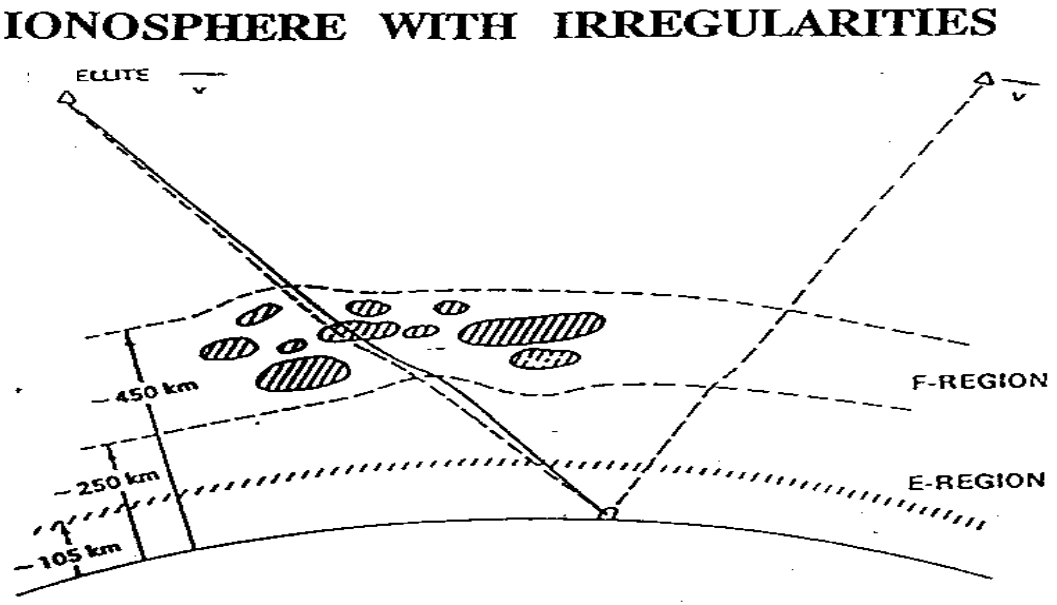
Scintillation

Scintillation can cause additional errors.





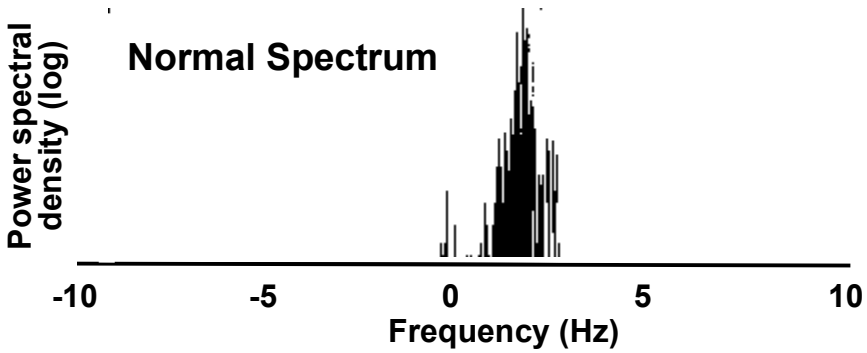
For GPS, the primary issue is loss of lock. For radars, the primary issue is degradation of coherent integration capabilities.

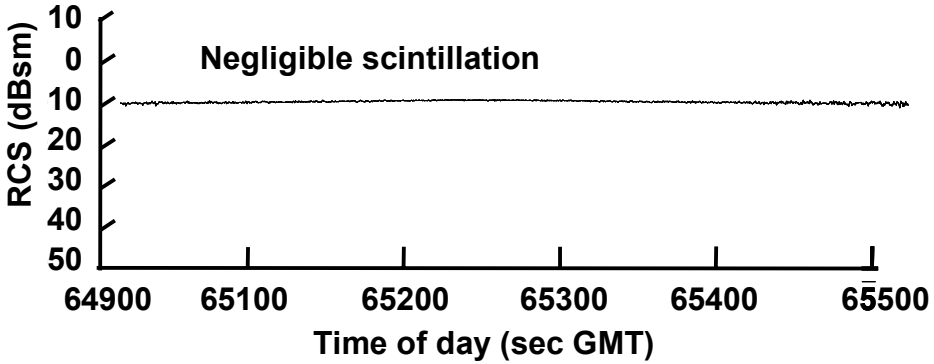


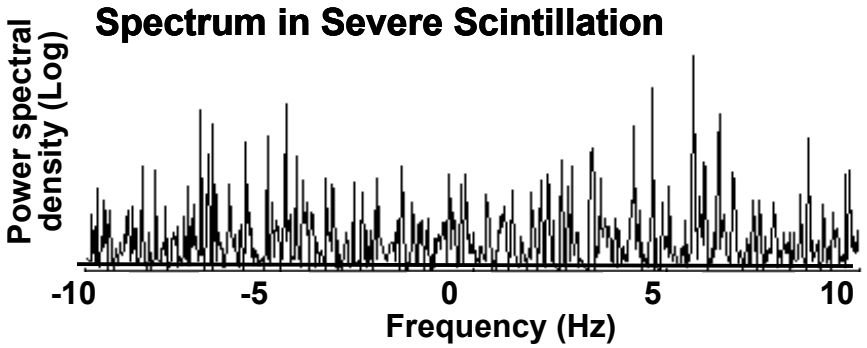
ALTAIR VHF Observations on CAL Sphere 2826:

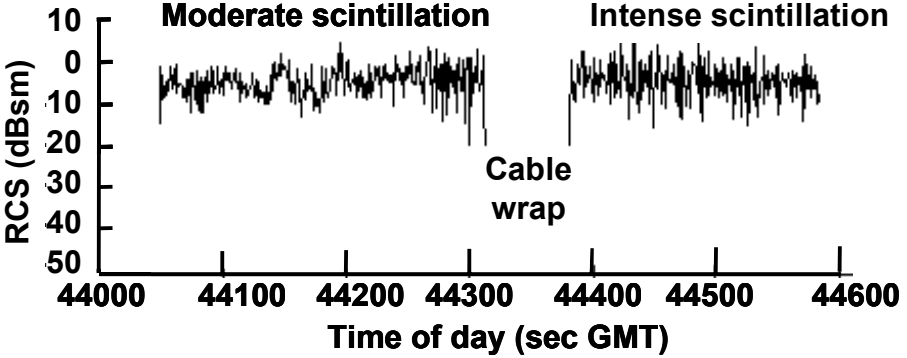
Normal Conditions versus Severe Scintillation

ALTAIR VHF Tracks
Calibration Sphere 2826
.5 m diameter, 850 km circular orbit









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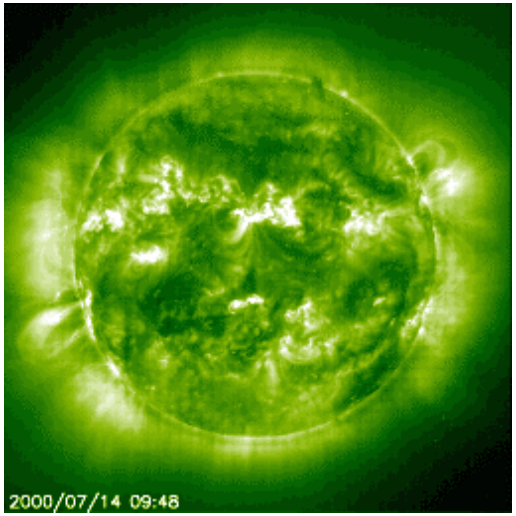

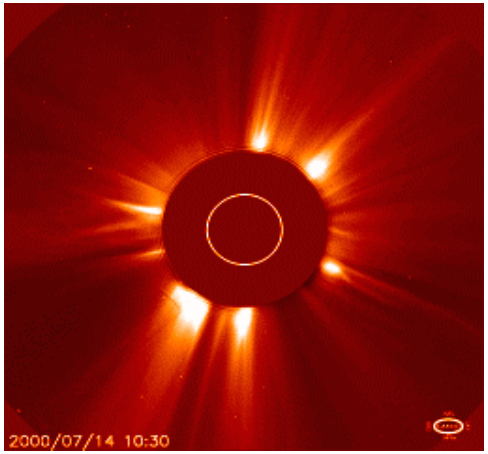

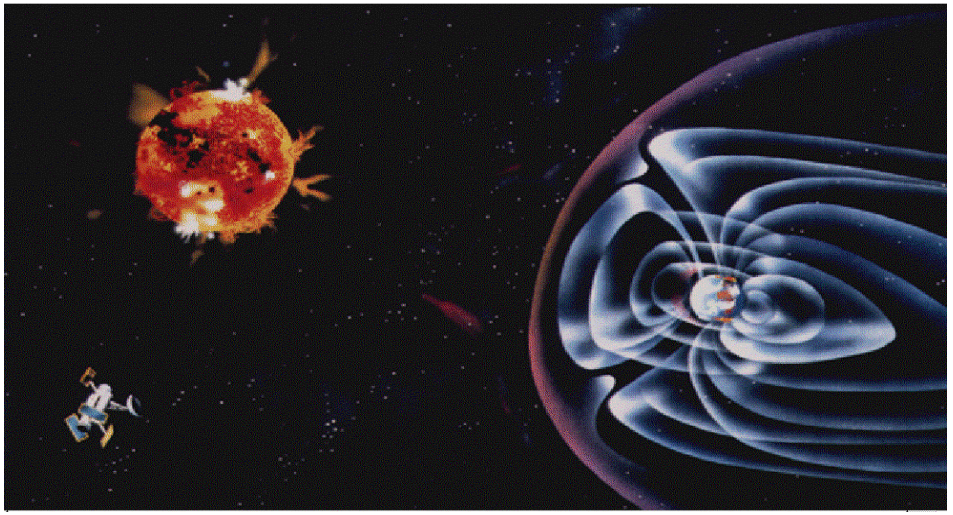

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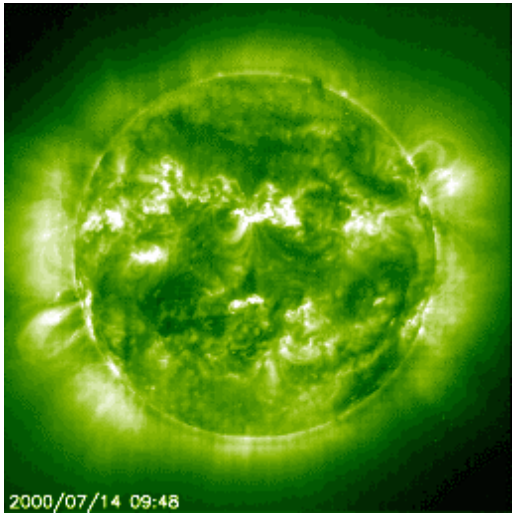
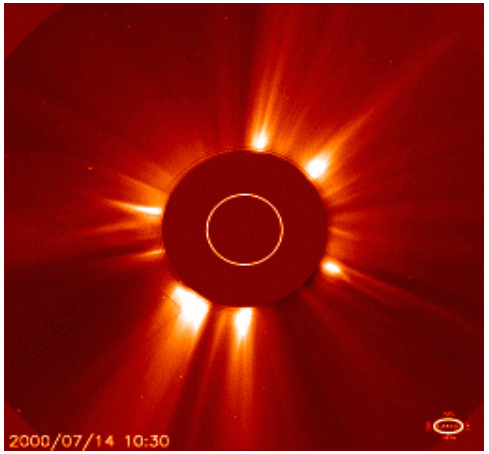
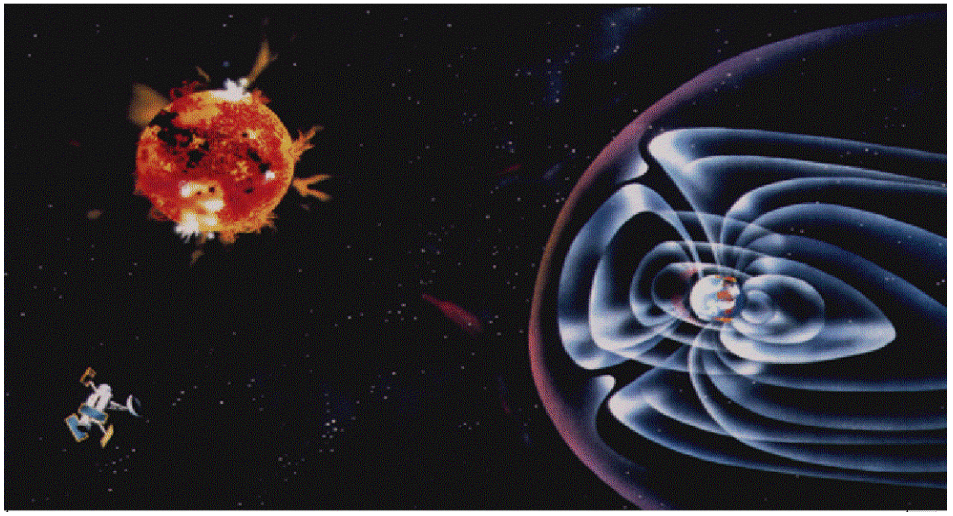
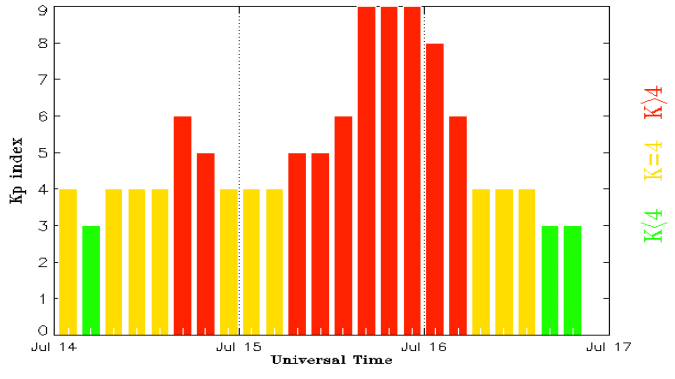




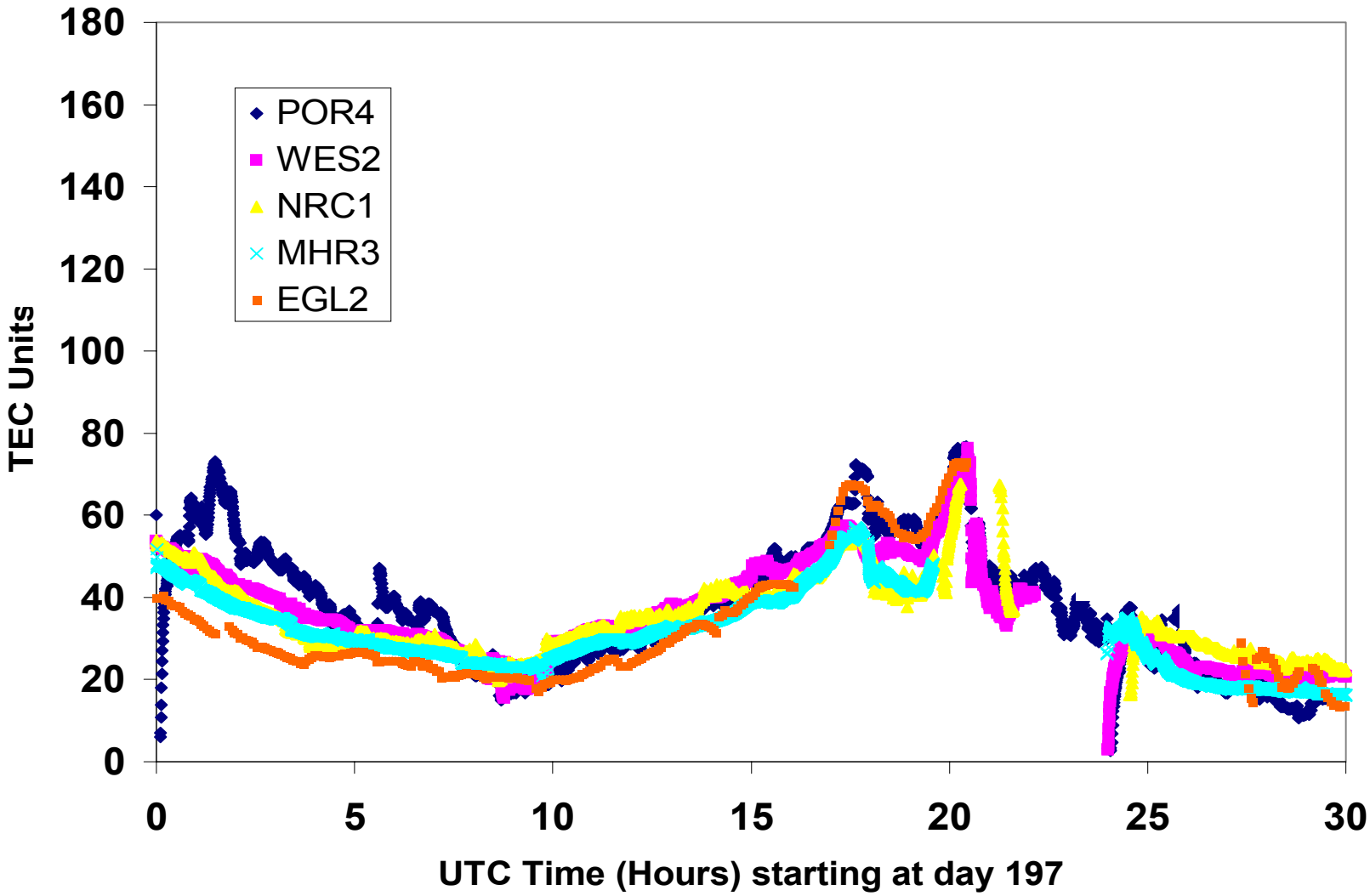


Est. Planetary Kp (3 Hr.) Begin: 2000 Jul 14 0000 UT

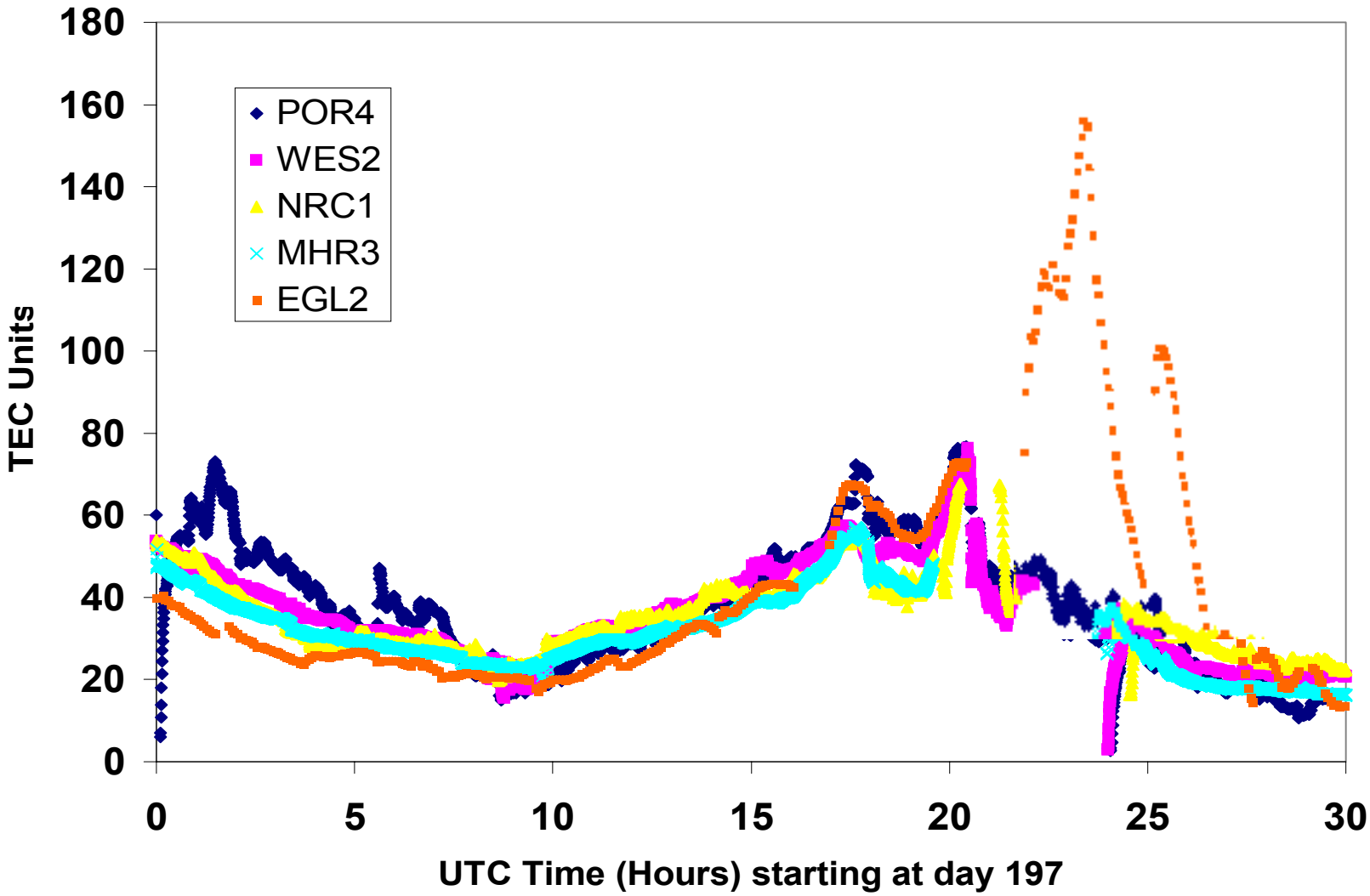


NOAA/SEC Boulder, CO USA

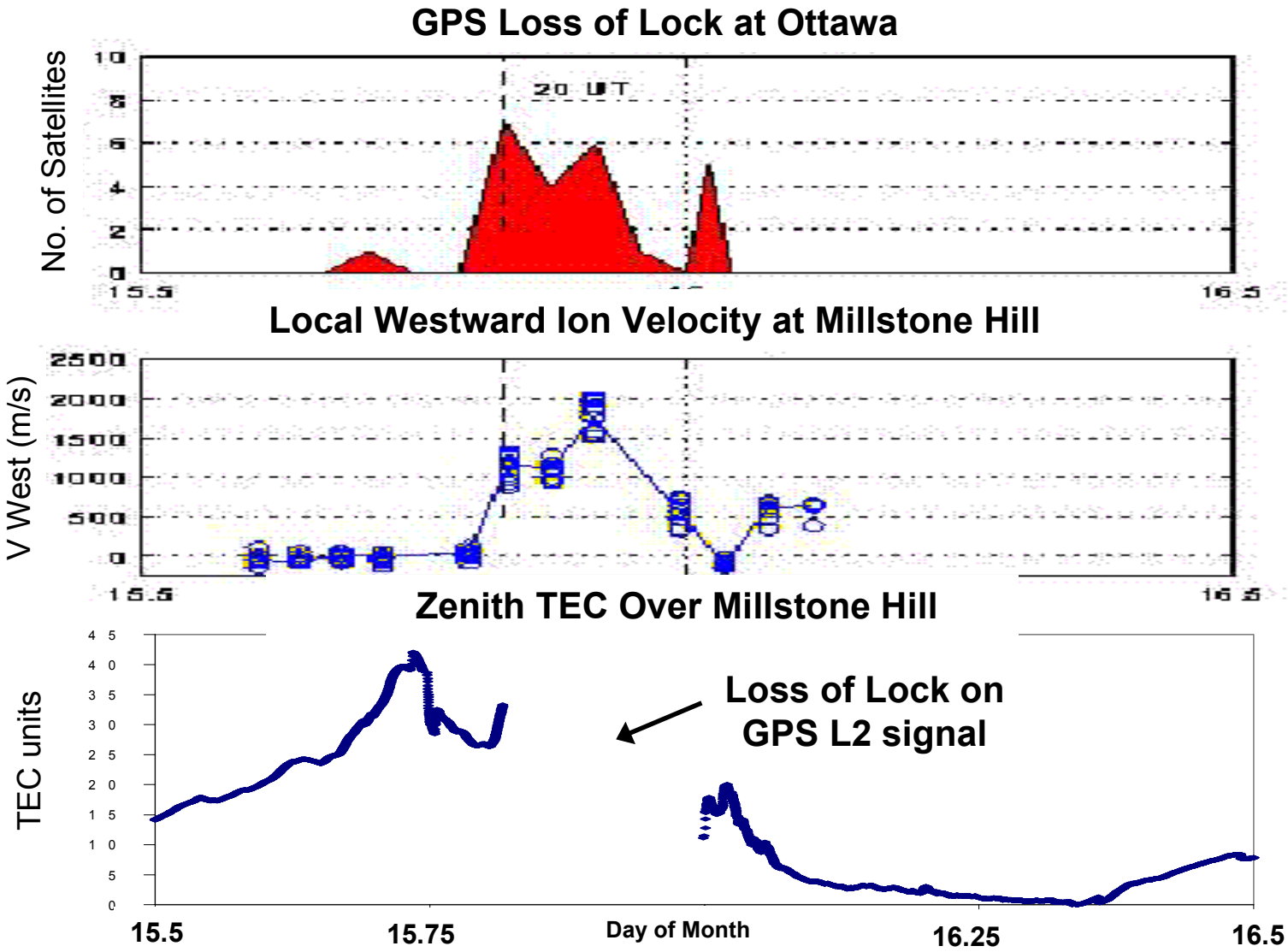
TEC Disturbances on 15 July 2000



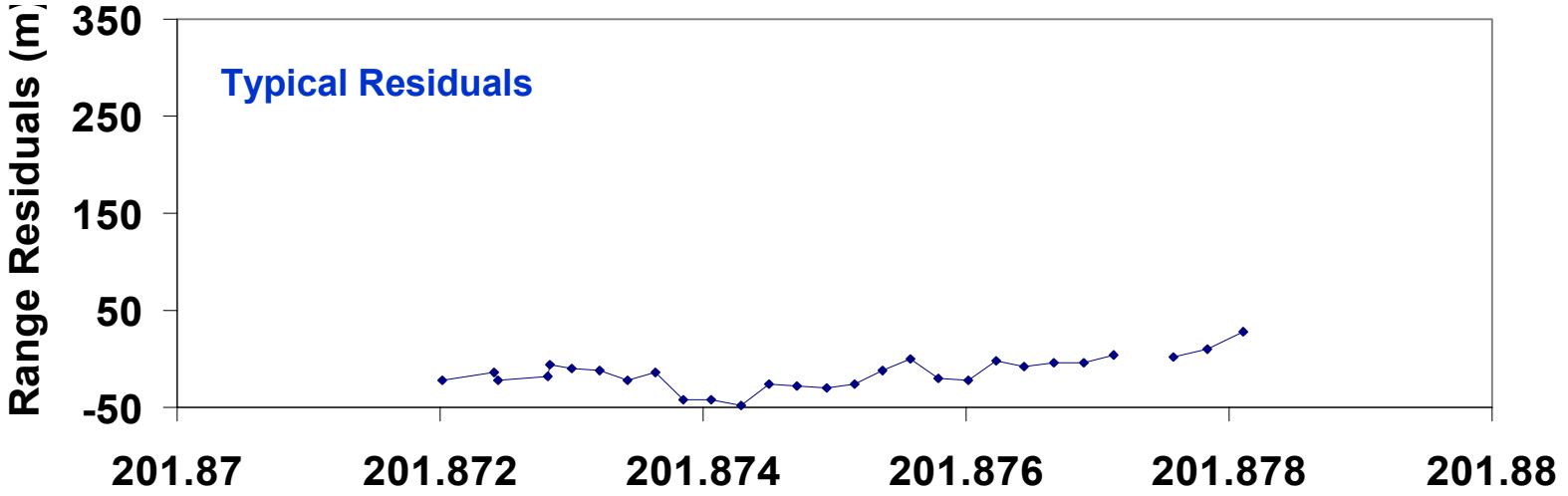
TEC Disturbances on 15 July 2000

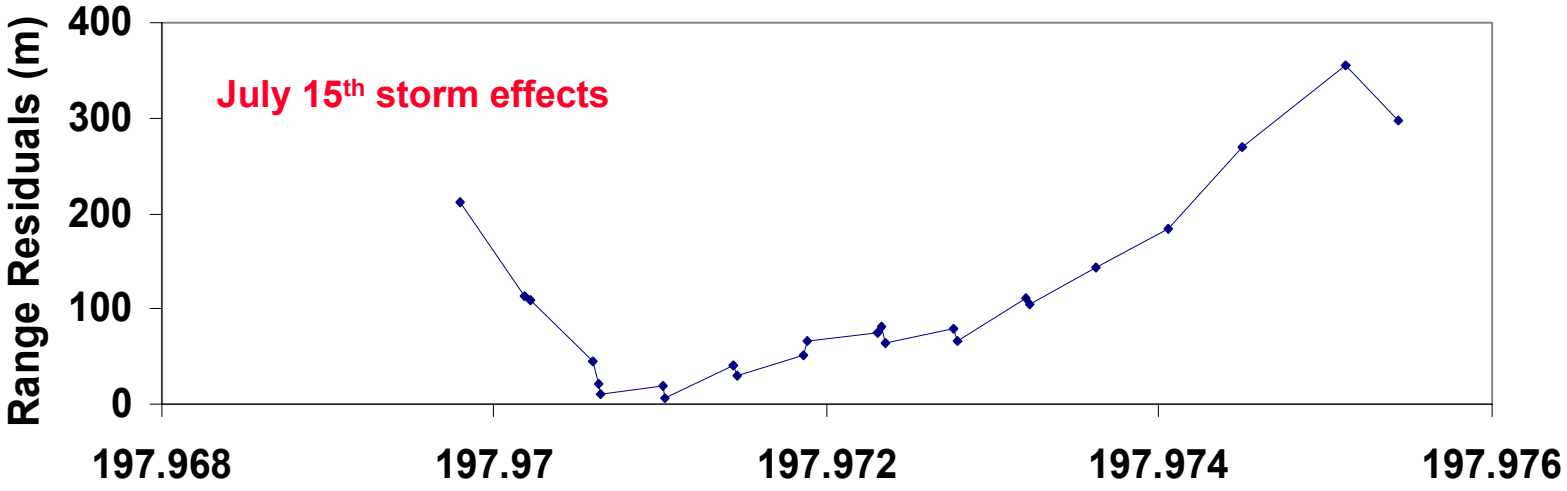


GPS Loss of Lock at Ottawa and Millstone Hill



Range Residuals on Calibration Sphere 7646
FPS-85 Florida





Summary

- Space-Based Visible sensor sensitive to proton radiation environment (e.g., SAA)
  - Transient effects (solar proton events) can degrade SBV performance
  - Long-term changes in the radiation environment may also affect performance of space-based sensors
- Ground-based radar measurements: ionosphere introduces errors
  - Range Delay and Angle Errors
  - Scintillation
- In general, geomagnetic storms make these errors larger and harder to model
- Understanding of space environment facilitates future space-based and ground-based systems